Refractive Index Measurement at TV Tower Prague

Martin GRÁBNER, Václav KVIČERA

Lab. of Microwave Links, TESTCOM, Hvožďanská 3, 148 01 Praha 4, Czech Republic

grabner@testcom.cz, kvicera@testcom.cz

Abstract. *Propagation related parameters are used for design and frequency planning of microwave networks. Atmospheric refractive index is the important parameter that influences the propagation of electromagnetic waves during so-called "clear sky" conditions.*

The refractive index measurement, which was launched in TESTCOM, is presented in this paper. Some statistical characteristics and their utilization are introduced.

Keywords

Propagation, refractive index, microwave networks.

1. Introduction

Performance and reliability of microwave links depends mostly on the quality of the propagation of electromagnetic waves between the transmitter and receiver. Worse propagation conditions lead to decreasing input power level, to increasing signal distortion and to growth of bit error ratio. Absorption and interference can cause fades on microwave links. The absorption fades are mostly due to hydrometeors (rain, snow, fog and hail); the interference fades are related to multipath propagation and the bending of electromagnetic waves in the atmosphere.

At the design and estimation of the quality of a microwave path, the probability (percentage of time) that the fade is higher than a considered level is calculated. The occurrence of hydrometeors and interference fades must be known for this estimation. There have been many experiments realized in TESTCOM focused on the influence of hydrometeors in the climatic conditions in the Czech Republic. The goal of the project of the refractive index measurement, which is presented in this paper, is to obtain statistical and dynamical characteristics of refractive index along the ground layer of the atmosphere, because these are related to the probability of multipath fadings during clear sky (i.e. no rain) conditions.

2. Propagation in Troposphere

One reason of multipath fadings is electromagnetic wave bending due to varying the refractive index distribution along the ground layer of the atmosphere. This distribution can be approximated linearly and specified by the height gradient of refractive index. The larger gradient, the larger wave bending (it results from Snell's law directly) and therefore the probability of a fade is larger too.

Refractive index at a certain altitude can be calculated from the parameters of the atmosphere using relations [1]:

$$N = \frac{77.6}{T}\left(p + \frac{4810\, e_H}{T}\right), \tag{1}$$

$$e_H = H\,\frac{6.1121\exp\left(\dfrac{17.502\,t}{t+240.97}\right)}{100}, \tag{2}$$

where p (hPa) is the atmospheric pressure, T (K) and t (°C) is the temperature and e_H (hPa) is the water vapor pressure that corresponds to the relative humidity of air H (%). Radio refractive index N is related to classical index n according to the equation:

$$N = (n-1)\cdot 10^{-6} \;. \tag{3}$$

An electromagnetic wave propagates over the rounded Earth's surface with a curvature. The ray of the wave is often transformed to the straight ray propagating over the Earth with an equivalent radius R_e due to practical advantages. Then, the ratio between the equivalent and standard radius of the Earth determines the degree of ray bending and is given by:

$$k = \frac{R_e}{R} = \frac{1}{1 + R\,\dfrac{\mathrm{d}N}{\mathrm{d}h}\,10^{-6}}, \tag{4}$$

where R (km) is the radius of the Earth and dN/dh (km^{-1}) is the gradient of refractive index. In standard atmosphere, dN/dh is -40 km^{-1} and k is 4/3.

3. Measurement

The device for the measurement of basic physical parameters of the atmosphere suitable for a deployment at TV Tower Prague was developed thanks to co-operation between TESTCOM and the Department of Electromagnetic Field of the Faculty of Electrical Engineering, Czech Technical University in Prague.

The equipment was installed in August 2001. Sensors of temperature and humidity are located 12 m, 126 m and 191 m over the ground level, sensor of pressure is in the height of 126 m only, other values of pressure are recalculated using standard height dependence. Optic fibers to a computer connect sensors and data are collected every 15 seconds. Fig. 1 shows the equipment in the laboratory of TESTCOM.

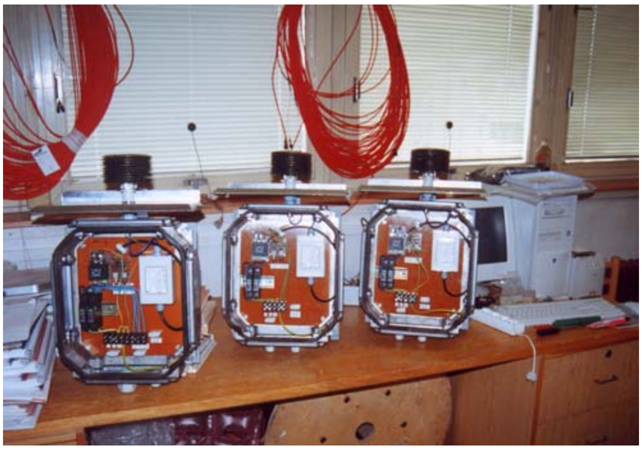

Fig. 1. Sensors of temperature and humidity with optic fibres

4. First Year Results

An important characteristic of the gradient of refractive index is its cumulative distribution, which determines the probability that quantity is lower than a considered value. Figures from 2 to 5 show the cumulative distributions of the gradient for individual months and given seasons from September 2001 to August 2002. Percentage of time P is expressed here instead of probability. The gradient was obtained from the difference of refractive indices at the heights of 12 and 126 meters. Label “100-P” in Figures 3 and 5 means the percentage of time for which the gradient is higher than a considered level.

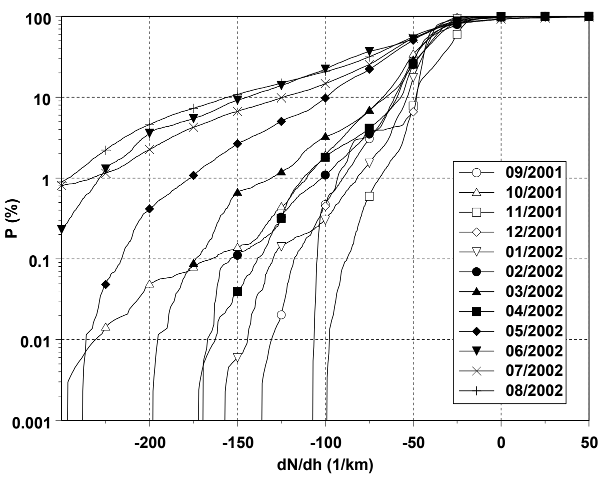

Fig. 2. Monthly cumulative distributions of gradient of refractive index – lower gradients

Parameters derived from the distributions are given in Tab. 1. The values of refractivity gradient, which are not exceeded for a certain percent of an average year, are compared with values according to the ITU-R model.

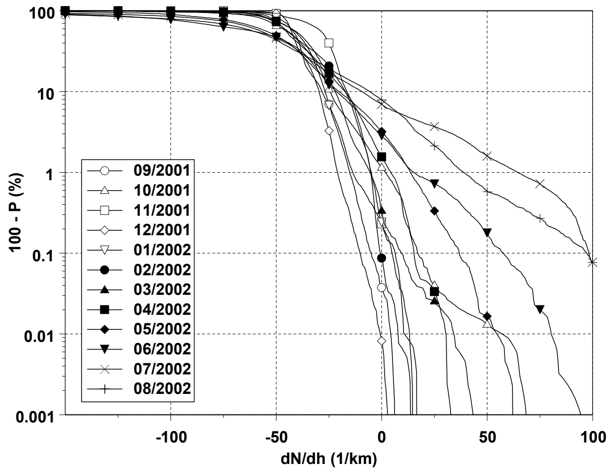

Fig. 3. Monthly cumulative distributions of gradient of refractive index – higher gradients

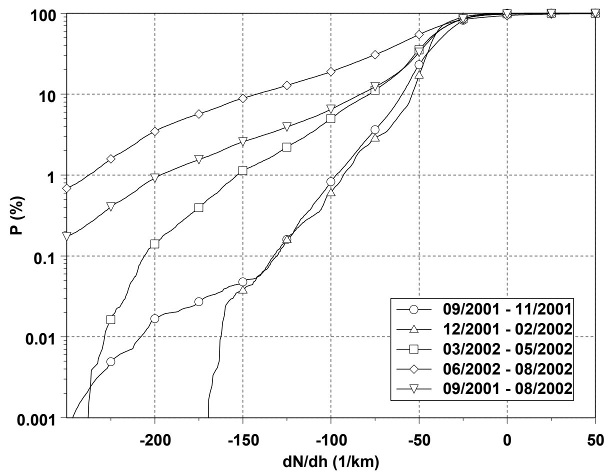

Fig. 4. Annual cumulative distribution of gradient of refractive index and four season distributions – lower gradients

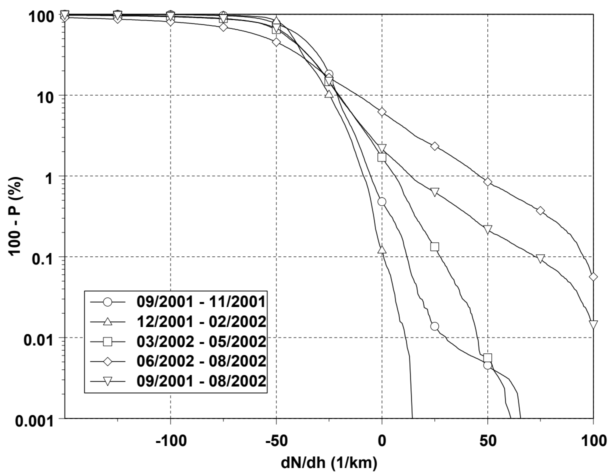

Fig. 5. Annual cumulative distribution of gradient of refractive index and individual season distributions – higher gradients

Percentage (%)	(d*N*/d*h*) (km^{-1})	$(dN/dh)_{ITU}$ (km^{-1})
1	-196.7	-289.9
10	-83.2	-143.8
50	-42.6	-49.6
90	-20.7	-23.3
99	13.5	5.7

Tab. 1. Comparison of obtained annual cumulative distributions and ITU-R model

Obviously, ITU-R model gives more pessimistic results, but note that estimated values of an *average year* distribution are considered in this model and distributions from one-year measurement are only used for this comparison.

5. Example of Use

Diffraction theory indicates that the direct path between the transmitter and receiver needs a clearance above ground of at least about 60% of the first Fresnel zone ($0.6F_1$) to achieve free-space propagation conditions. Therefore the first step is to determine the antenna heights required for the appropriate median value of the factor k (Earth's curvature) and $1.0F_1$ (100% of the first Fresnel zone) clearance over the highest obstacle. Median value of k corresponds to the 50% value of the refractivity gradient, in our case $(dN/dh)_{50\%} = -42.6\ km^{-1}$ (see Tab. 1) and using relation (4) $k_{50\%} = 1.37$. This value is close to the mean value of $k = 4/3$ in the standard atmosphere.

Extreme values of the refractivity gradient sometimes appear. When the gradient is higher than the standard one, the factor k and the equivalent Earth's radius decrease and the obstacle is relative higher against the microwave ray. Free space conditions can be corrupted. The second step is to check the antenna heights required for the value k not exceeded for 99.9% of time and $0.0F_1$ or $0.3F_1$ clearance (according to the shape of an obstacle) over an obstacle. From annual distribution (Fig. 5) it can be obtained $(dN/dh)_{99.9\%} = 72.6\ km^{-1}$ and $k_{99.9\%} = 0.68$. A higher antenna fixing should be used then.

The refractivity gradient not exceeded for 1% (see Tab. 1) is now being used for the estimation of multipath fading occurrence in the ITU-R recommendation [2].

6. Conclusion

The measurement of atmospheric parameters in the ground layer and the assessment of the refractive gradient have not been carried out in the Czech Republic so far. Statistic characteristics of the refractive gradient in the ground layer of the atmosphere were obtained and parameters for planning microwave links were derived.

Results obtained are unique and show the extreme values of the refractivity gradient appear mostly in summer. Observing days with the occurrence of extreme gradients and a comparison with multipath fading events will be made in the future.

Acknowledgements

Support for the GAČR project "Performance and reliability of advanced telecommunication systems using millimetre wavelengths in the Czech Republic" (No. 102/01/0029) is gratefully acknowledged.

References

[1] MAZÁNEK, M., PECHAČ, P., VOKURKA, J. *Antény a šíření vln (Antennas and propagation of waves).* Praha: ČVUT Publishing, 1998.

[2] Rec. ITU-R P.530-9 Propagation data and prediction methods required for the design of terrestrial line-of-site systems. Geneva, 2001.

About authors...

Martin GRÁBNER was born in Prague in 1976. He graduated from Czech Technical University in Prague in 2000. He has been working at the Laboratory of Microwave Links in TESTCOM.

Václav KVIČERA was born in Poděbrady in 1948. He received MSc. and PhD. degree from the Czech Technical University in Prague. He is Senior Researcher at the Laboratory of Microwave Links in TESTCOM. His research is concentrated on radiowave propagation over 1 GHz on fixed links.